Development of Amorphous Nitride Cathodes for Large Area MCP Detectors

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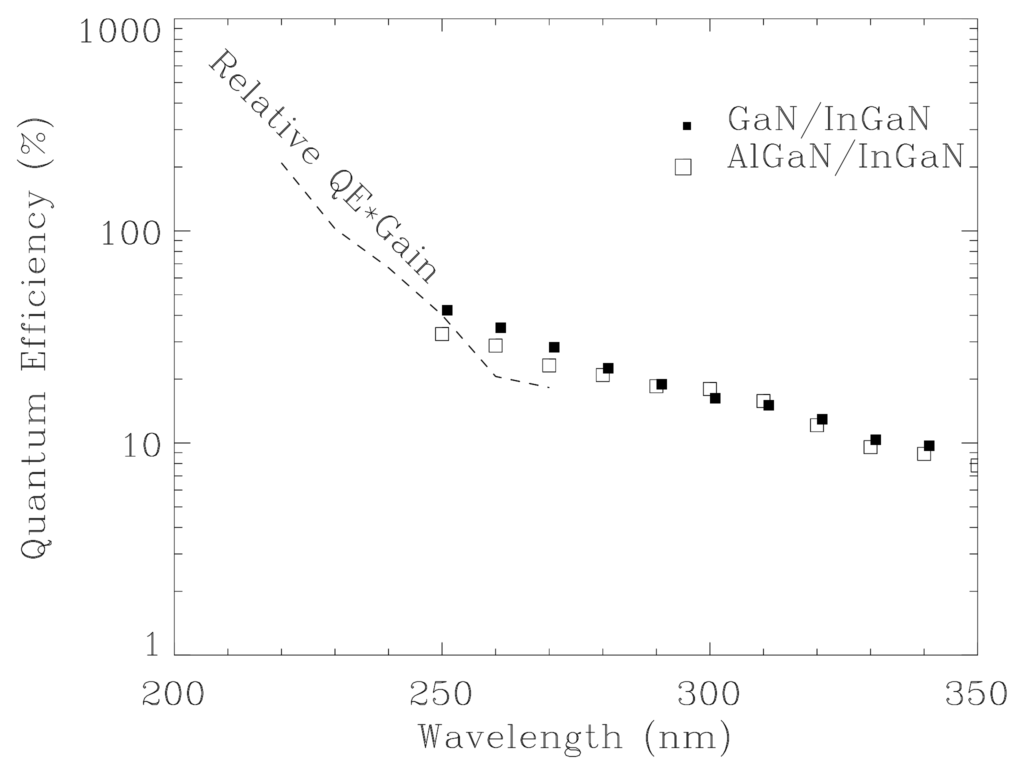
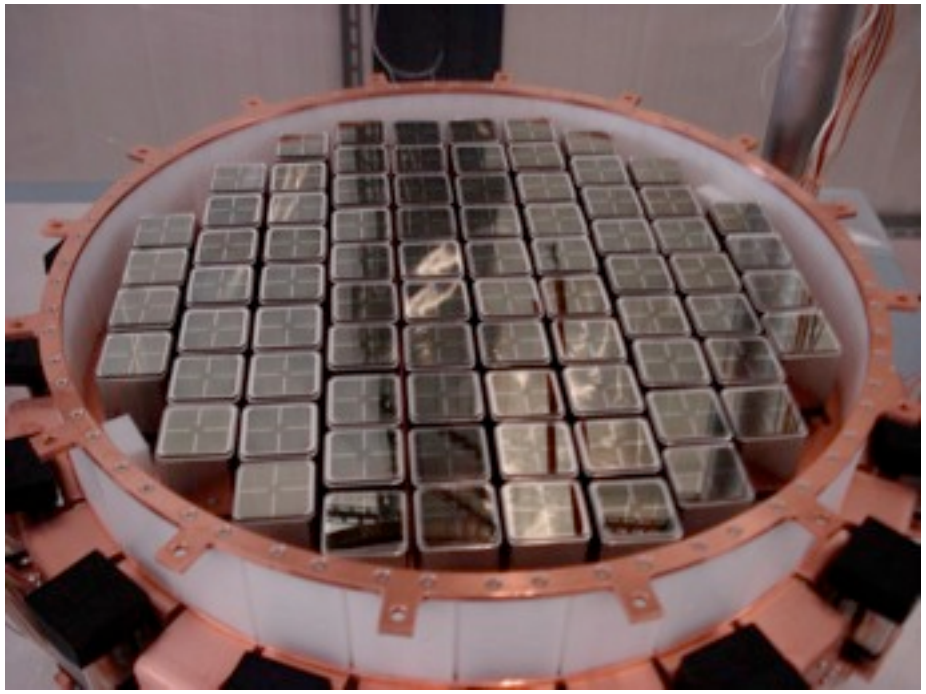
WU Photocathode Project Overview

- Nitride semiconductors are ideally suited for use in photocathode devices operating in the UV and blue spectral range with a bandgap tunable from 0.8 - 6.2 eV
- Epitaxial crystalline structures have exhibited high quantum efficiency in this range
- Large-area lower-cost photocathodes with wavelength sensitivity extending throughout the blue range are needed for HEP and water Cherenkov detectors.
- Amorphous semiconductor nitride photocathodes have the potential to meet these requirements, allowing direct deposition at low-T on different substrates (e.g., Sapphire, MgF2, Scintillators, MCPs)
- High QE, low background photocathodes operating in the hard UV are also needed for noble gas detectors in HEP experiments (e.g., direct DM detection)

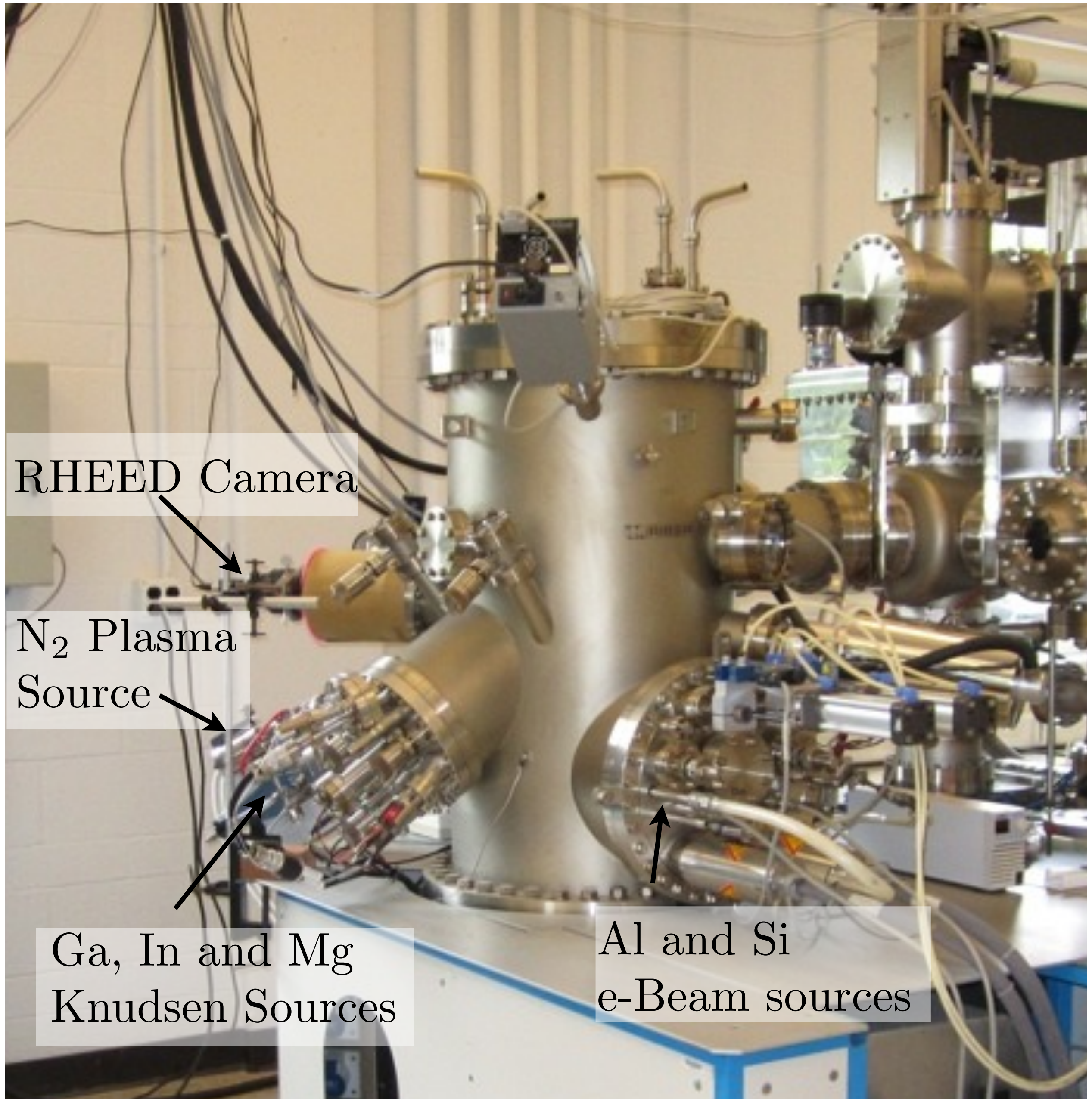


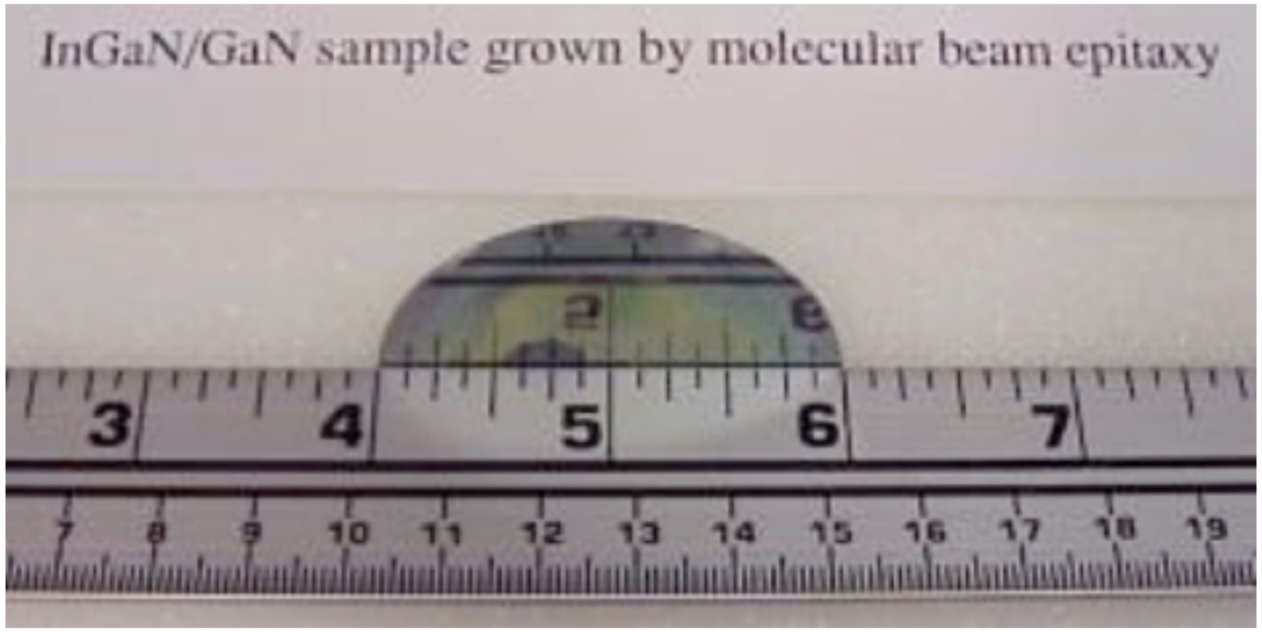


Xenon-100 PMT array. Liquid Xenon scintillation peaks at 175nm, Argon at 125nm

MBE Growth System

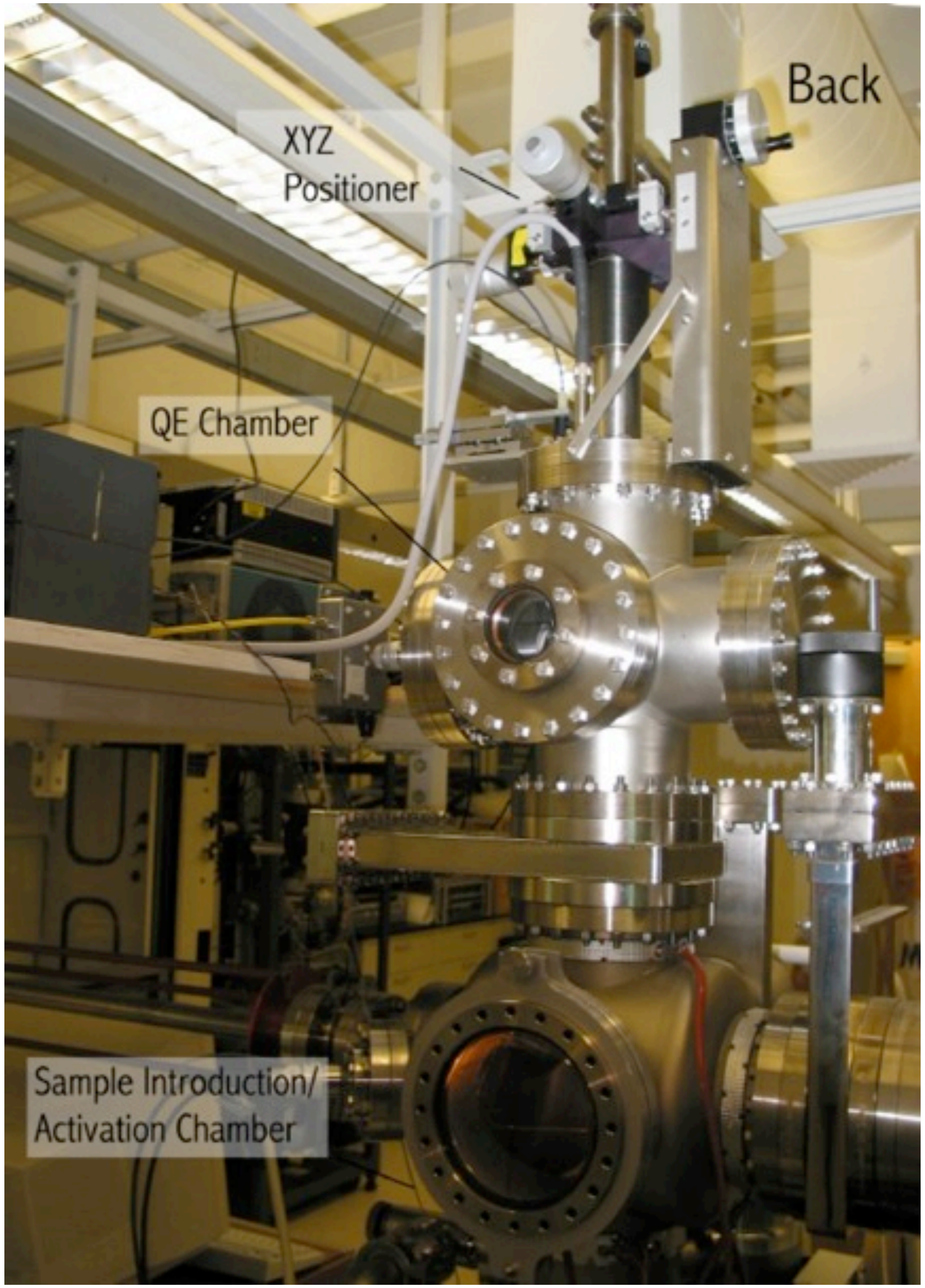
- MBE utilizes a UHV growth chamber with a rotating, heated substrate and shuttered beams from the different sources.   Our Nitride system also includes a Nitrogen plasma source





Our system currently has the capability of growing wafers up to 3 inch in diameter

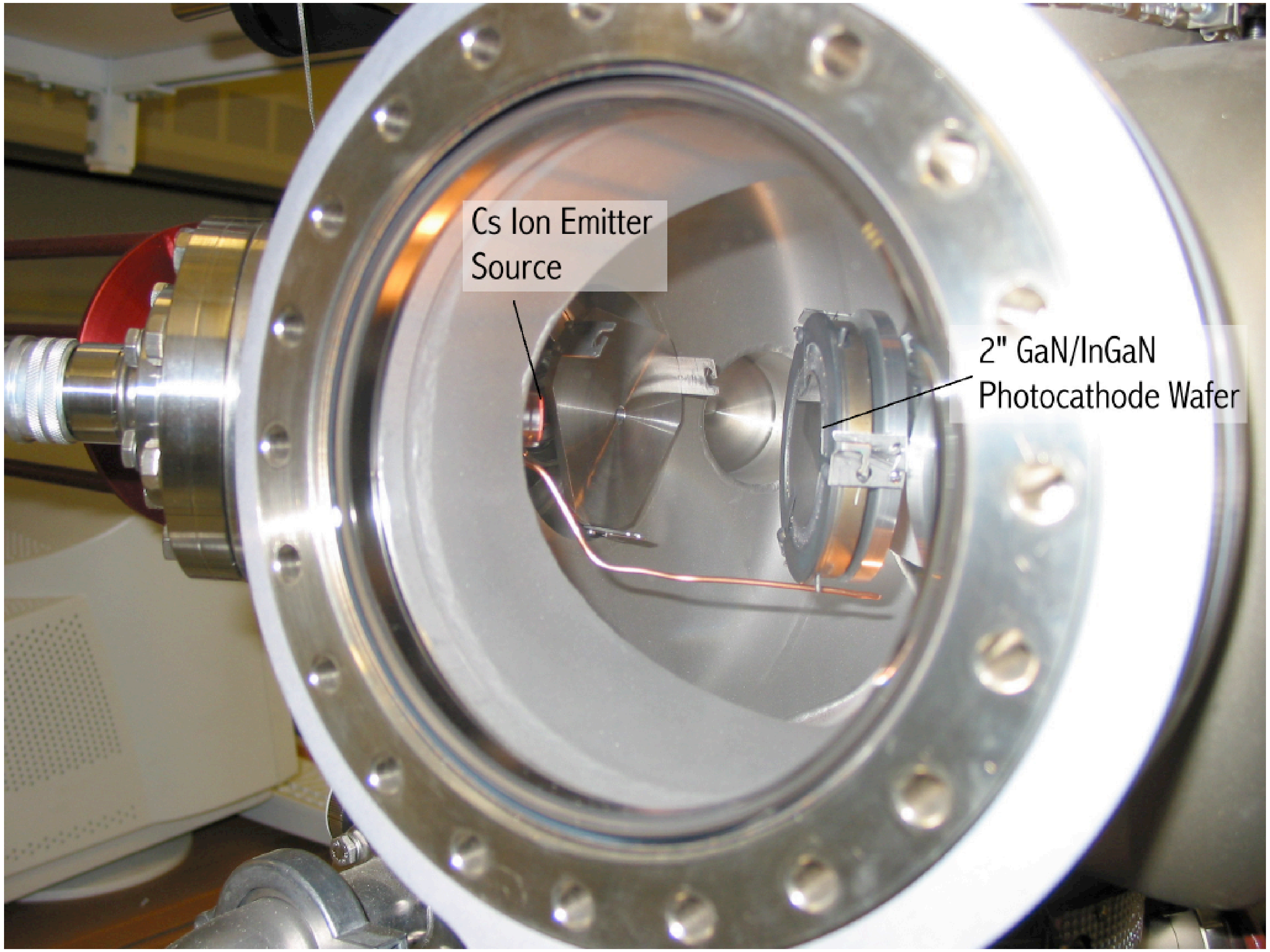
Activation and QE Measurement System



- WU system includes a number of vacuum transfer stages for in-situ Cs activation, docking with electron multipliers and readout electronics as well as in-situ QE measurements.

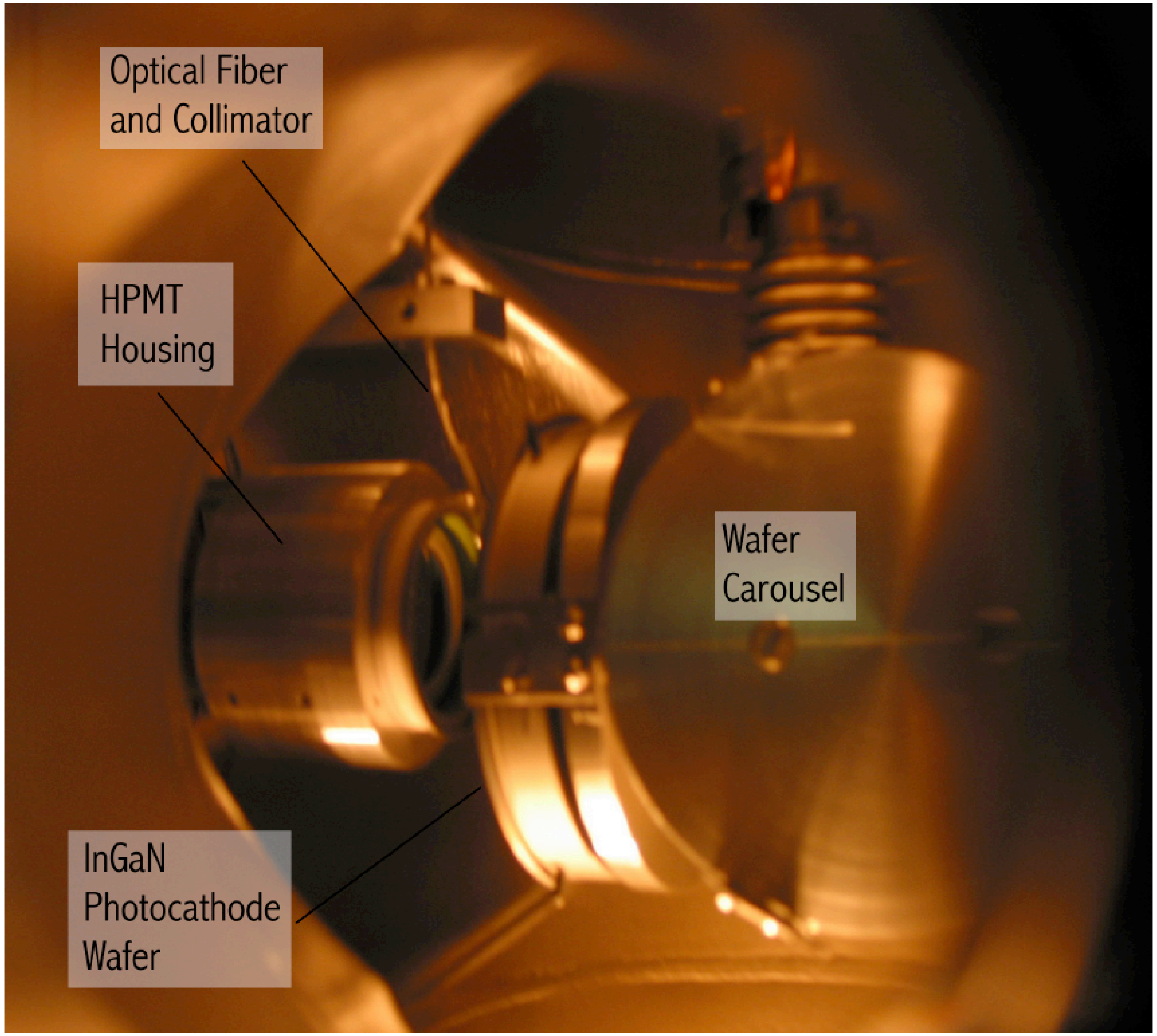
- *Unique UHV transfer capability for cathode growth, device integration and testing without removing from vacuum*

Cesium Activation



- Ion-beam source for Cs activation. Cs exposure monitored by Ion current

QE Measurement System



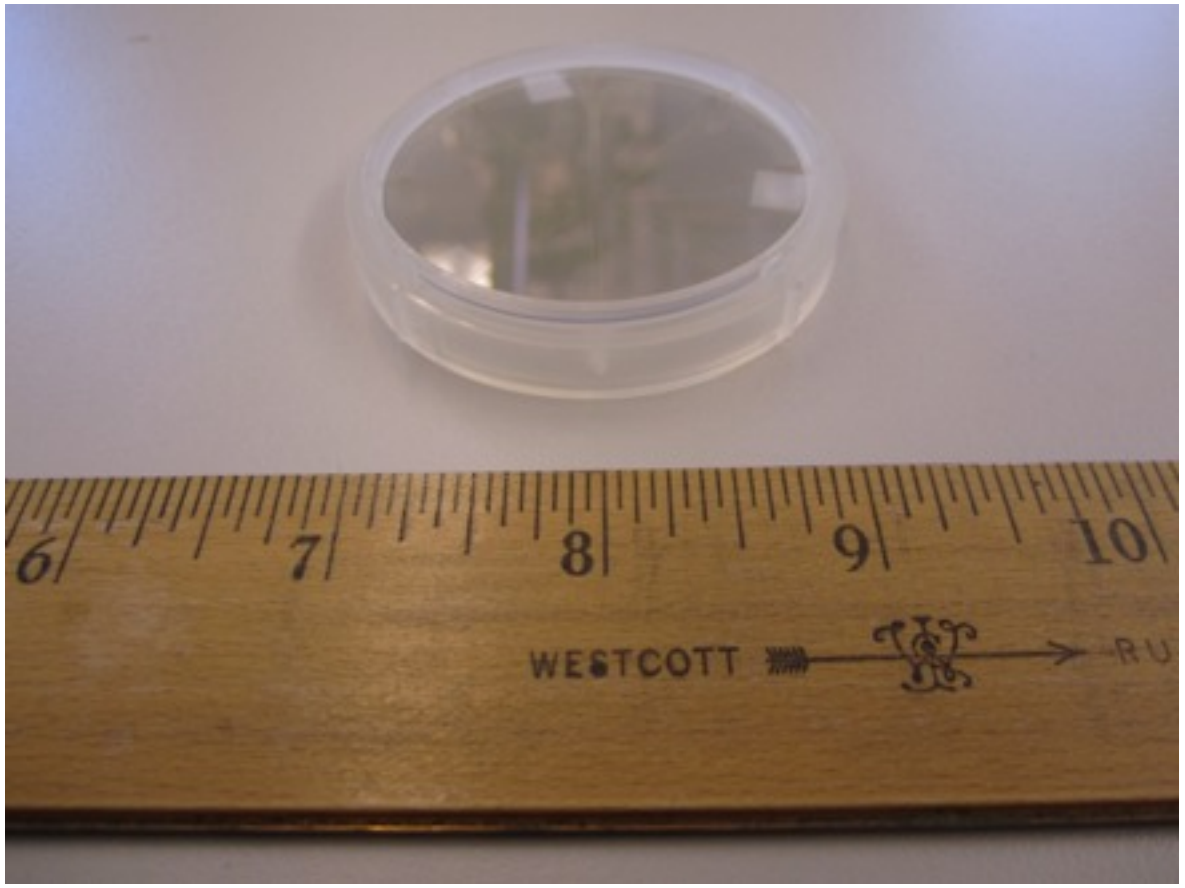
- Hybrid phototube with 7-pin photodiode array, and two independent HVs for gain and cathode bias. External low-noise preamplifier and data acquisition system connected by vacuum feedthroughs

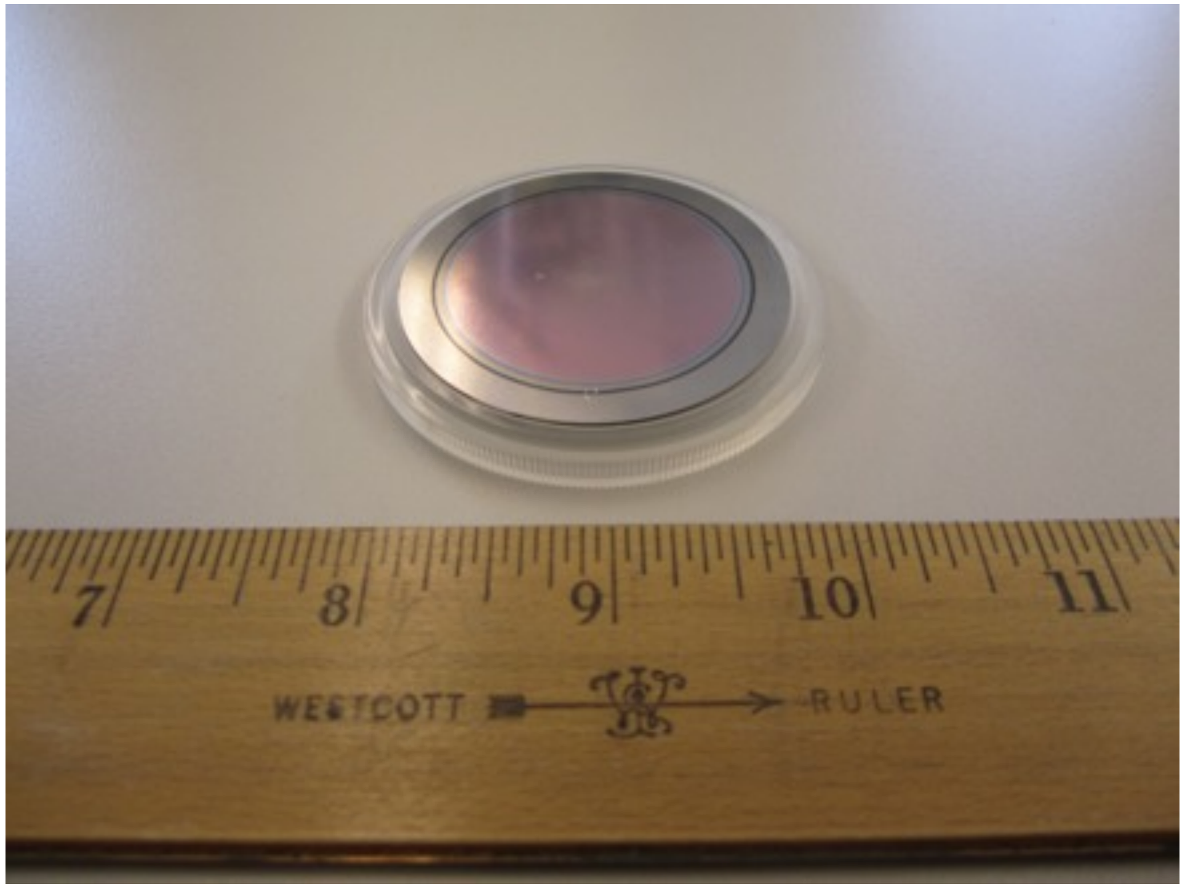
- UV-fiber coupled signal from monochromatic pulsed light source

Objectives

- Optimize amorphous nitride photocathode materials for high quantum efficiency.
- Extend wavelength response further into the blue using higher Indium concentration.
- Explore alternative substrates for fabrication of thin film amorphous nitride photocathodes.
- Examine methods to restore cathode surfaces exposed to air, or the use of protective coatings for transporting cathodes to other laboratories.
- Implement tube sealing capabilities within our UHV growth/testing chamber.
- Modify QE vacuum stage for MCP measurements.
- Direct cathode deposition on MCP and in-situ measurements.
- MCP for transfer to ANL or SSL.
- New substrate preparations for Cathode growth and further optimization of growth parameters.

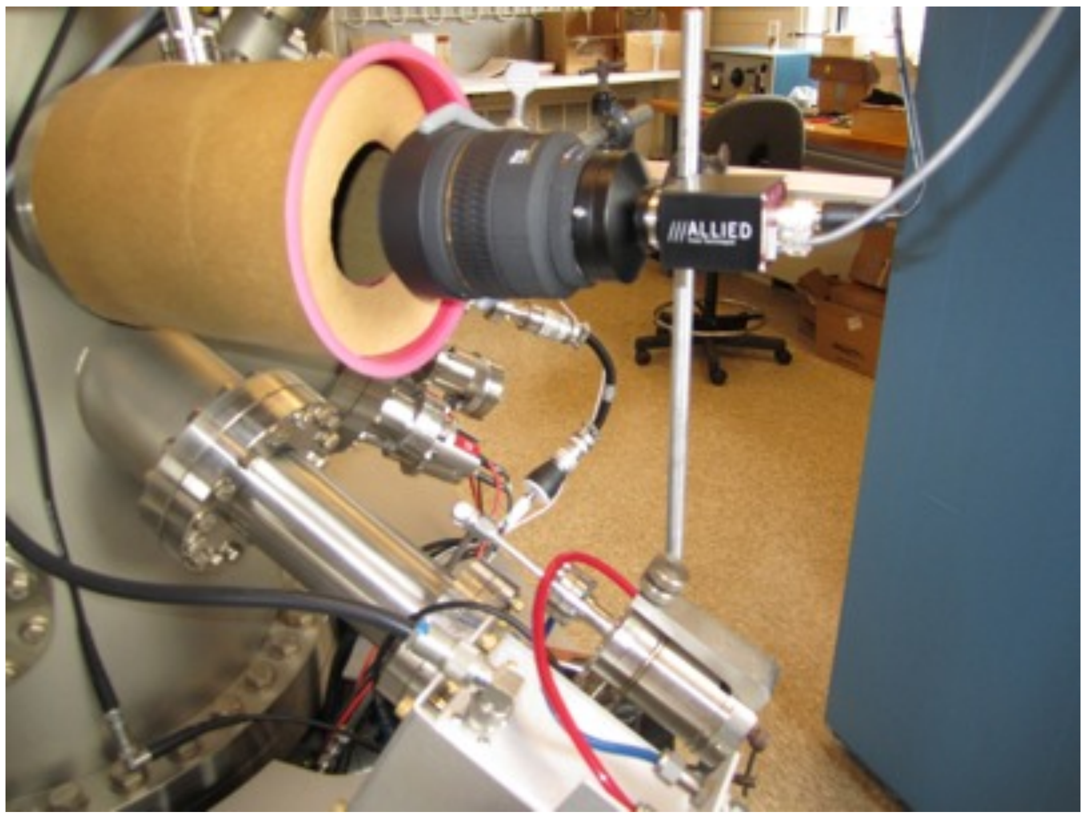
Amorphous InGaN Cathodes





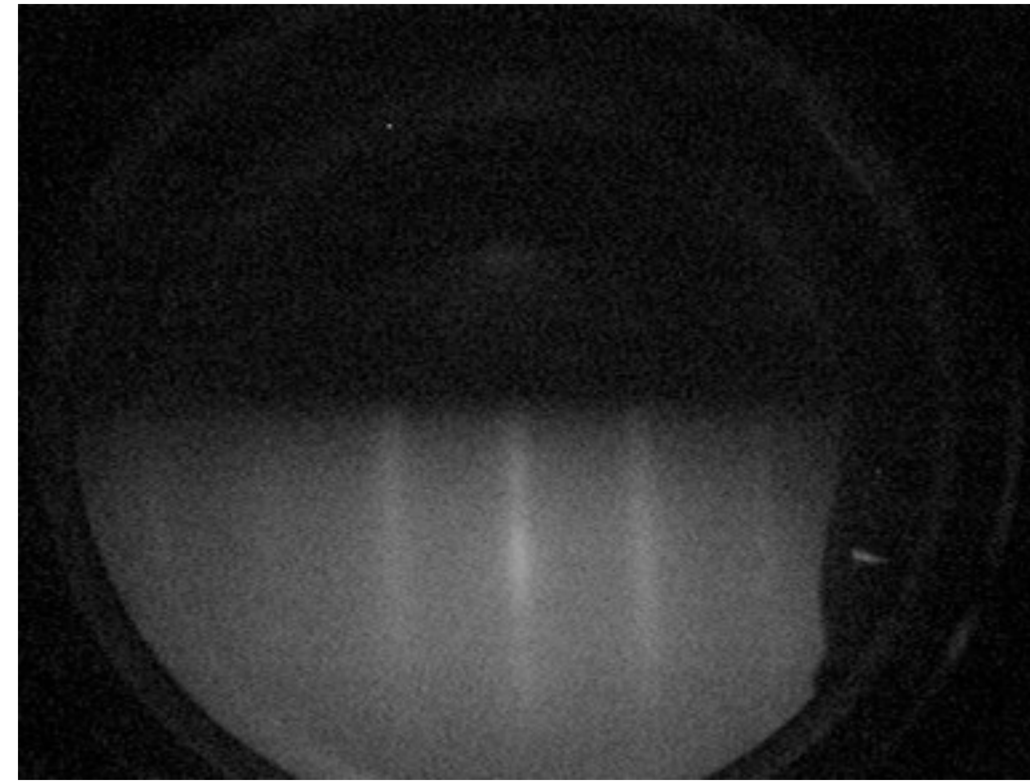
- We have grown amorphous InGaN on sapphire (left) and on stainless steel (right).
- Consistent with the theoretical prediction that a-GaN should have a clean gap, we have achieved similar QEs to epitaxial (single-crystal) structures.
- Now have the capability to grow efficient cathodes at low temperature on a variety of substrates.

RHEED Measurements



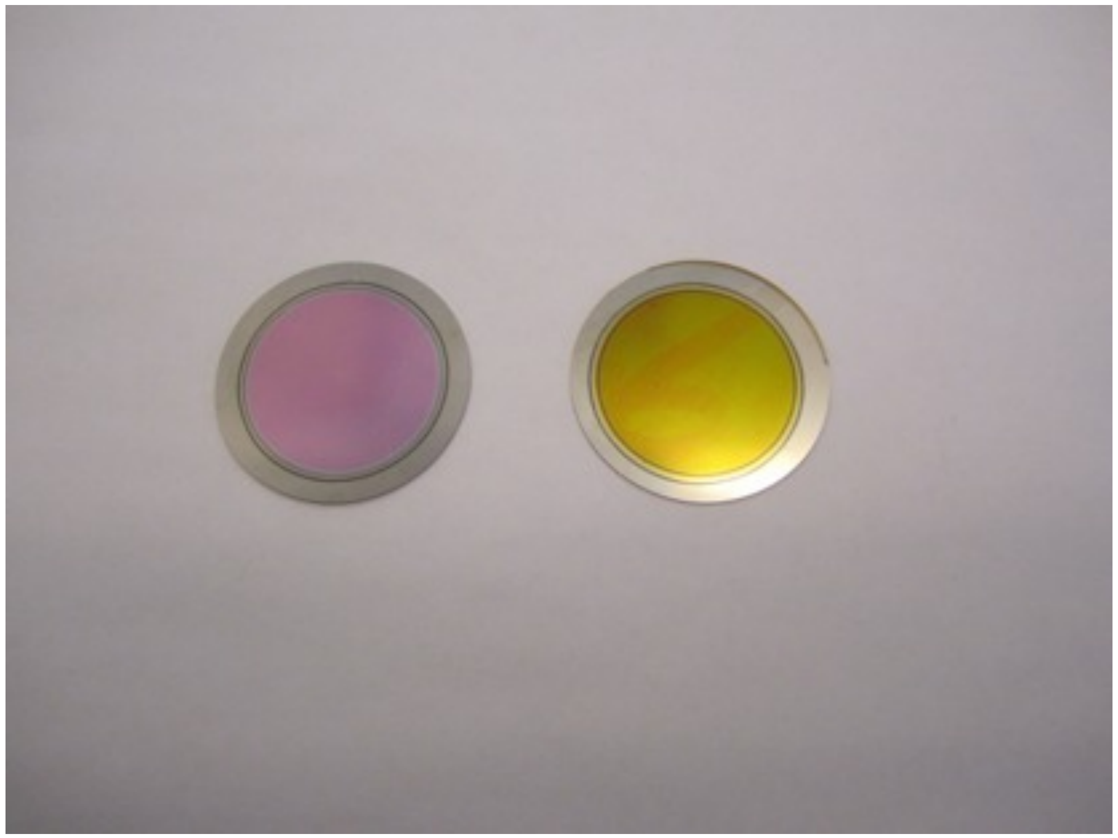
Upgraded RHEED system using a wide-field lens, and high-speed low-light interline digital camera and new LINUX CPU and DACQ software.

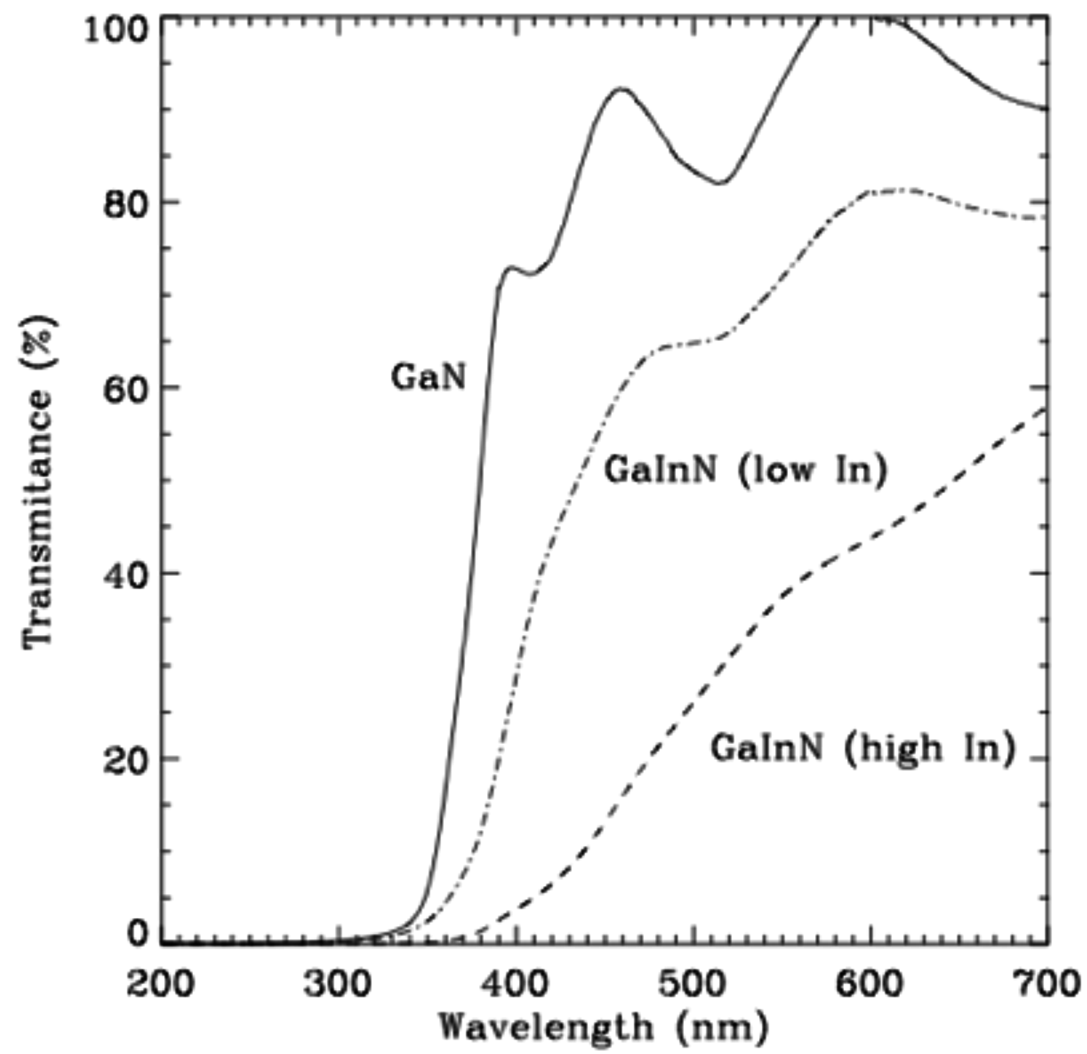
epitaxial InGaN



amorphous InGaN

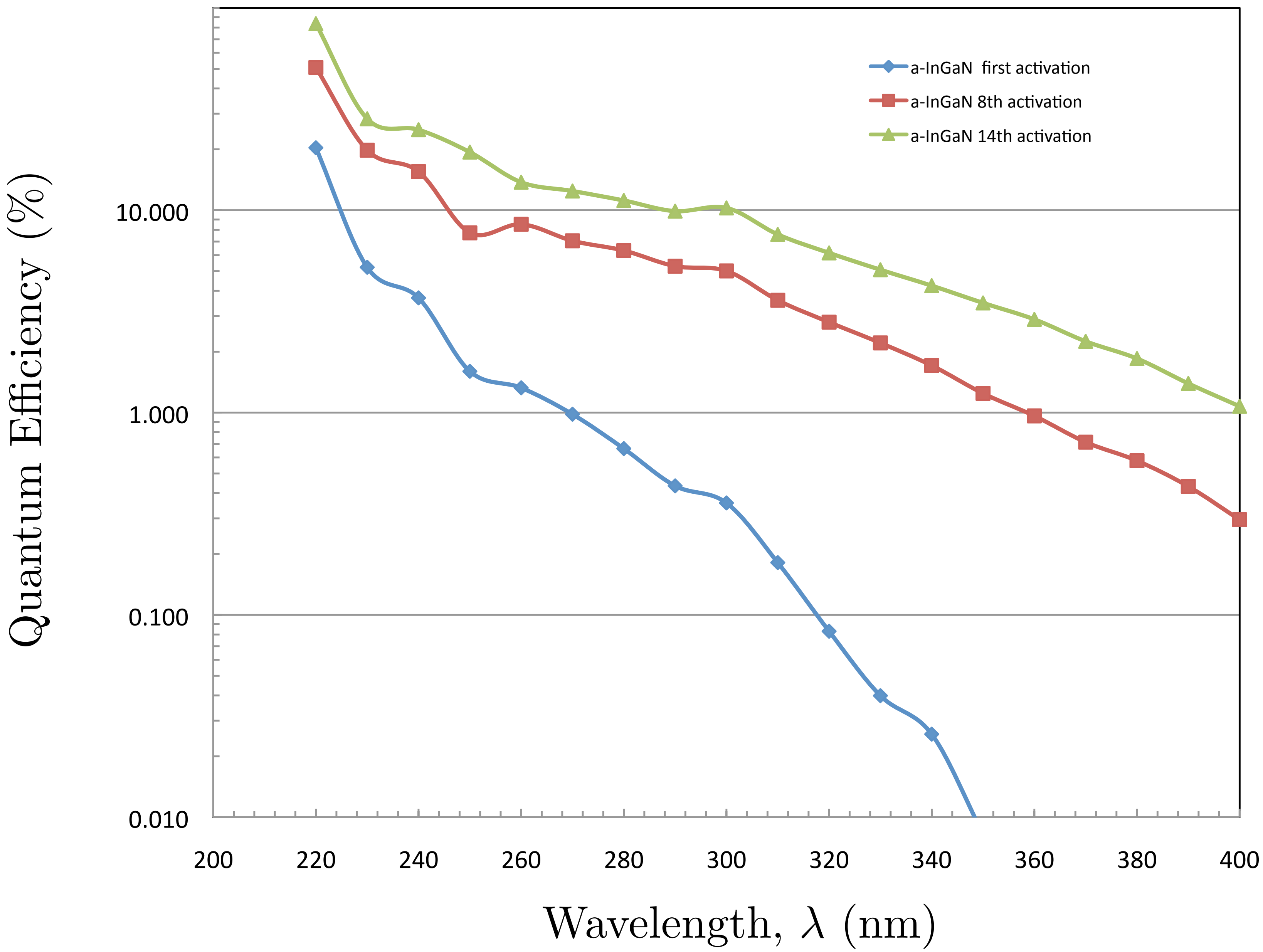
Increased In Concentration





- Cathodes were fabricated with increased In (25% and 50%).
- Absorption edge shift apparent in reflected light (high In on right).

QE for a-$In_{0.5}Ga_{0.5}N$



Cs Activation

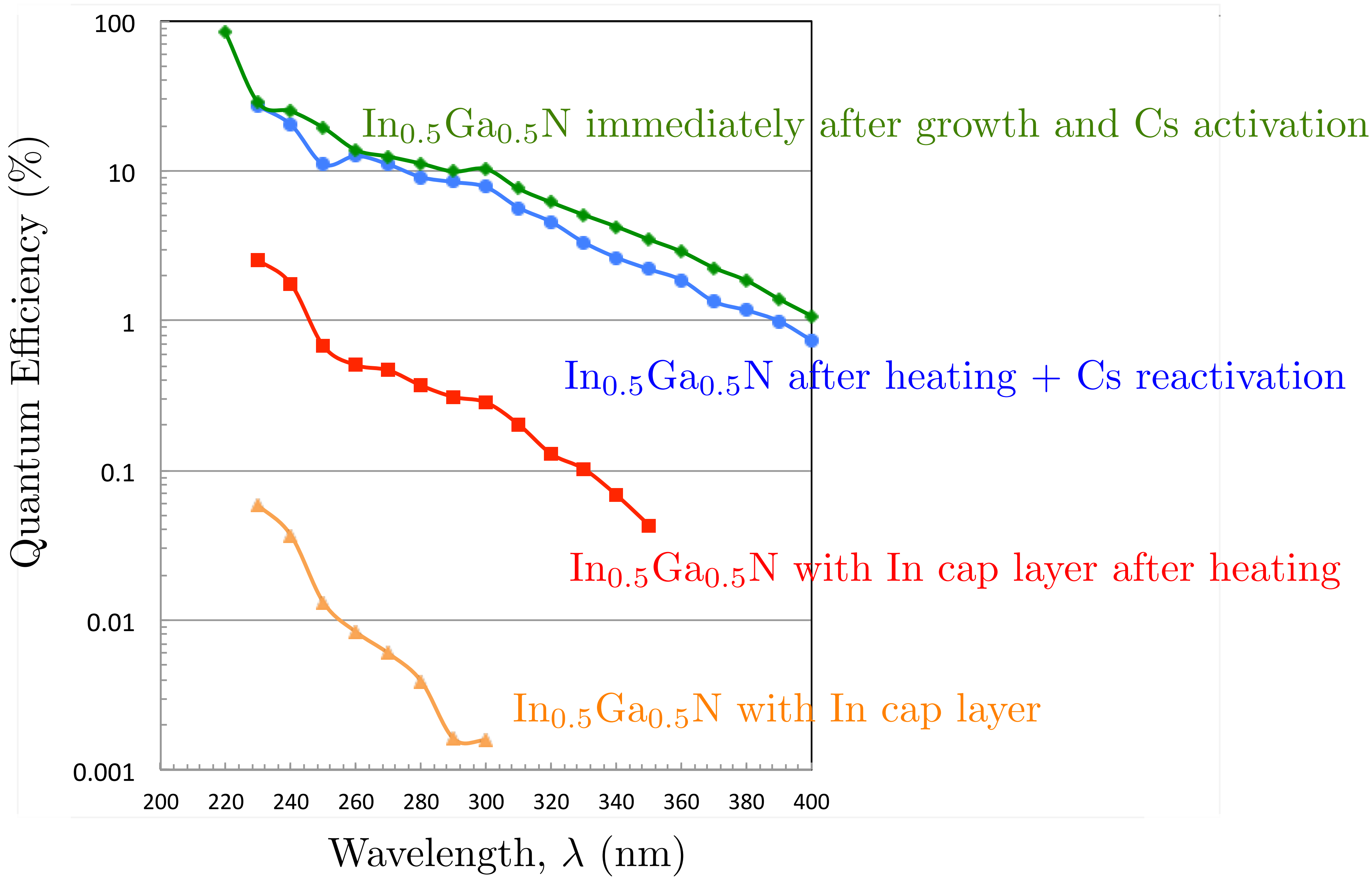
Amorphous GaInN Photocathode Quantum Efficiency Ratios
after activation with Cs

Wavelength	2nd/1st Cs	3rd/2nd Cs	4th/3rd Cs	5th/4th Cs	6th/5th Cs	7th/6th Cs	8th/7th Cs
220 nm	1.34	1.22	1.1	1.23	1.19	1.11	1.1
270 nm	1.47	1.44	1.32	1.26	1.35	1.14	1.19
310 nm	1.92	1.75	1.61	1.43	1.43	1.26	1.18
320 nm	2.44	1.75	1.64	1.61	1.4	1.28	1.19
330 nm	3.06	2.2	1.9	1.55	1.52	1.31	1.19
350 nm				1.74	1.59	1.43	1.27
370 nm				2.15	1.76	1.54	1.33

- Very little aging effect (QE stays the same one day later!) - early exposures actually show increase with time after activation (diffusion?)
- Continued improvement with repeated Cs activation, larger improvements in long wavelengths.
- Indicates that QE is still limited by surface, not bulk properties.

Results of In Capping of a-$In_{0.5}Ga_{0.5}N$ Cathode

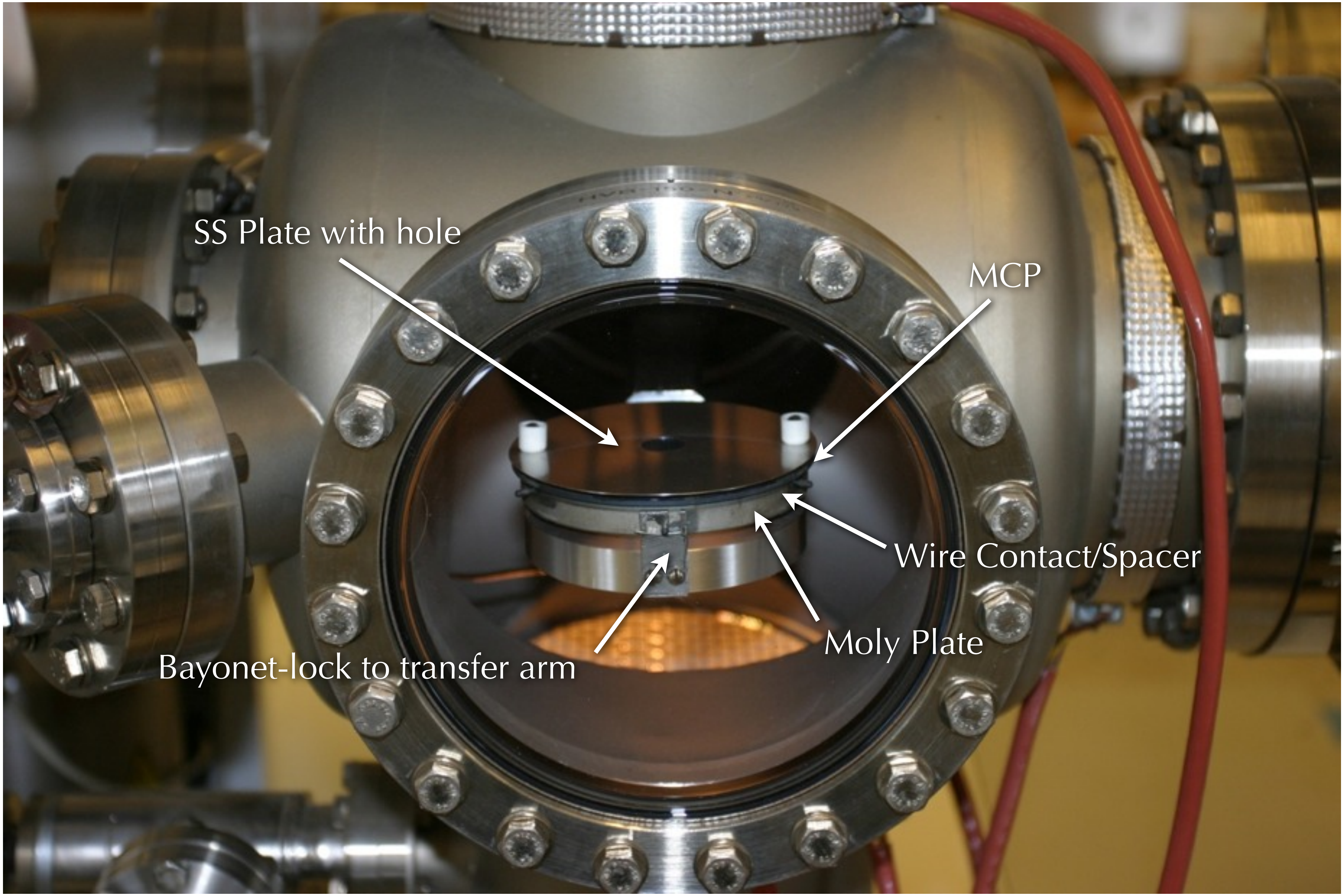
- Capped cathode was exposed to air (no bag or hermetic container) for several months, then capping stripped off with heat.
- Possible mechanism for maintaing surface quality during cathode transfer



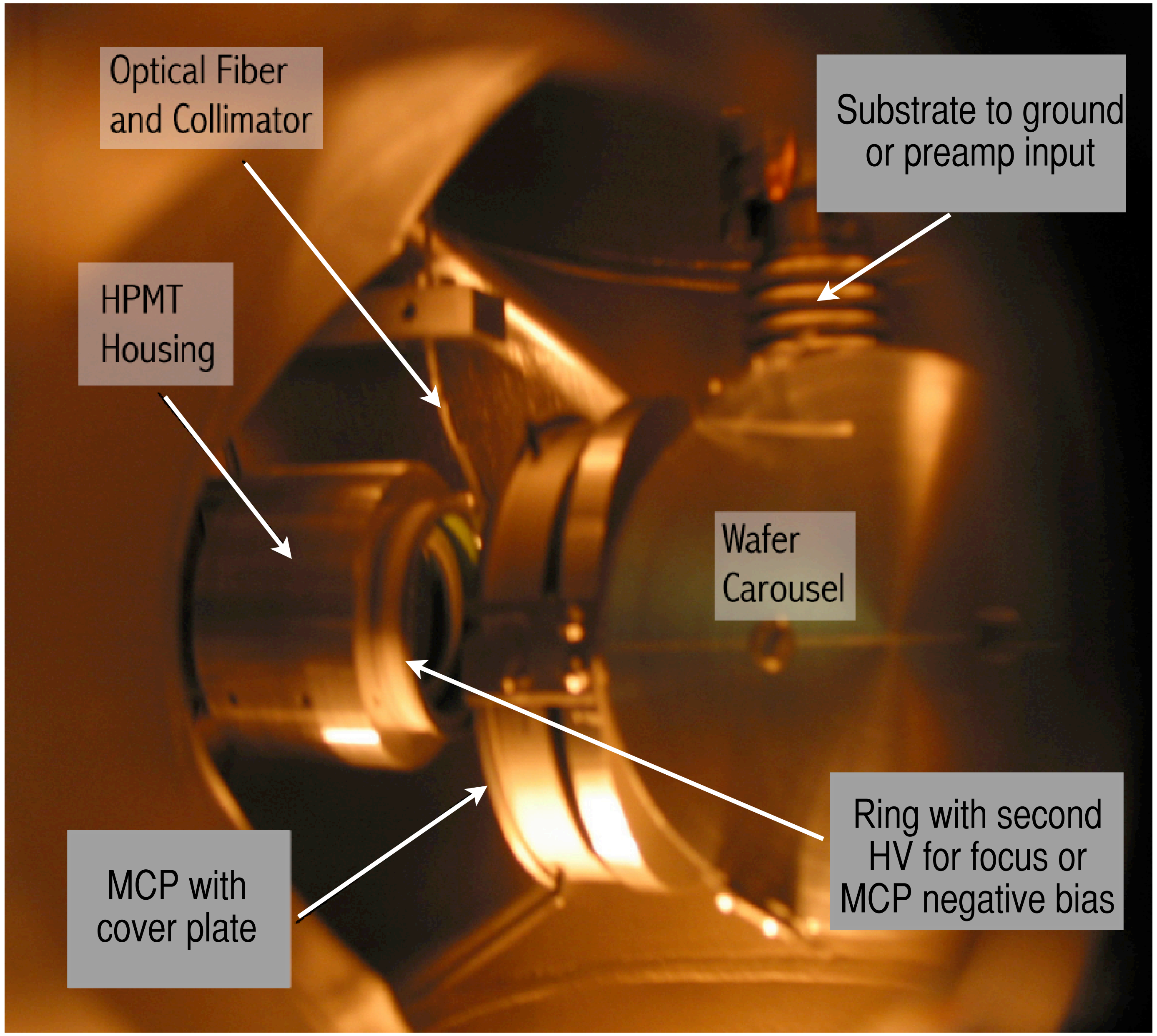
Work in Progress

- Demonstrated ability to measure MCP response with system.
- Added a capability for more precise in-situ measurements of resistance.
- Ready to deposit amorphous cathodes on MCPs and measure response (without removing from UHV).
- Working on improvement in our UV measurement capabilities by adding a Deuterium lamp, vacuum monochrometer, high-speed optical chopper, flip-mirror system for comparison with NIST-calibrated photodiode.
- Continue development of in-Vacuum tube sealing system, including development of new methods for forming reduced-oxide indium wire.

MCP Testing in Vacuum Chamber

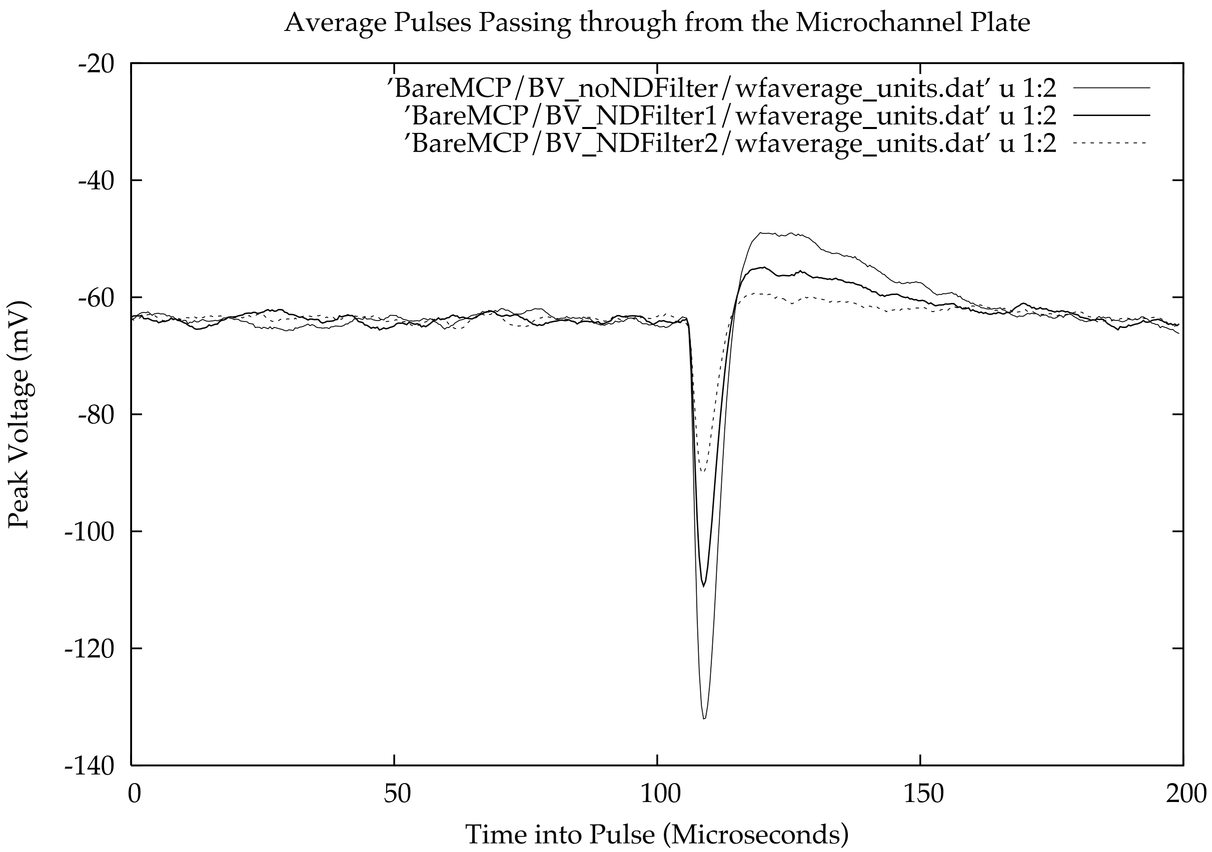


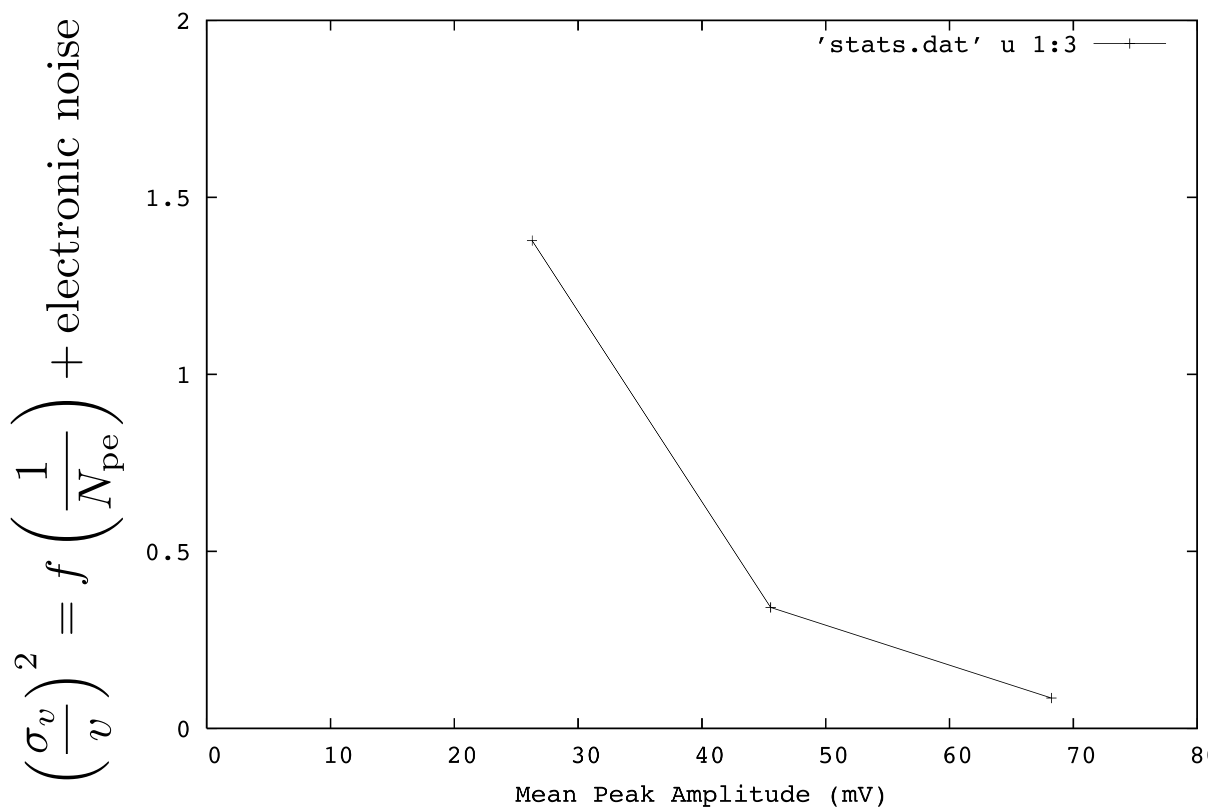
MCP/HPMT Measurement System



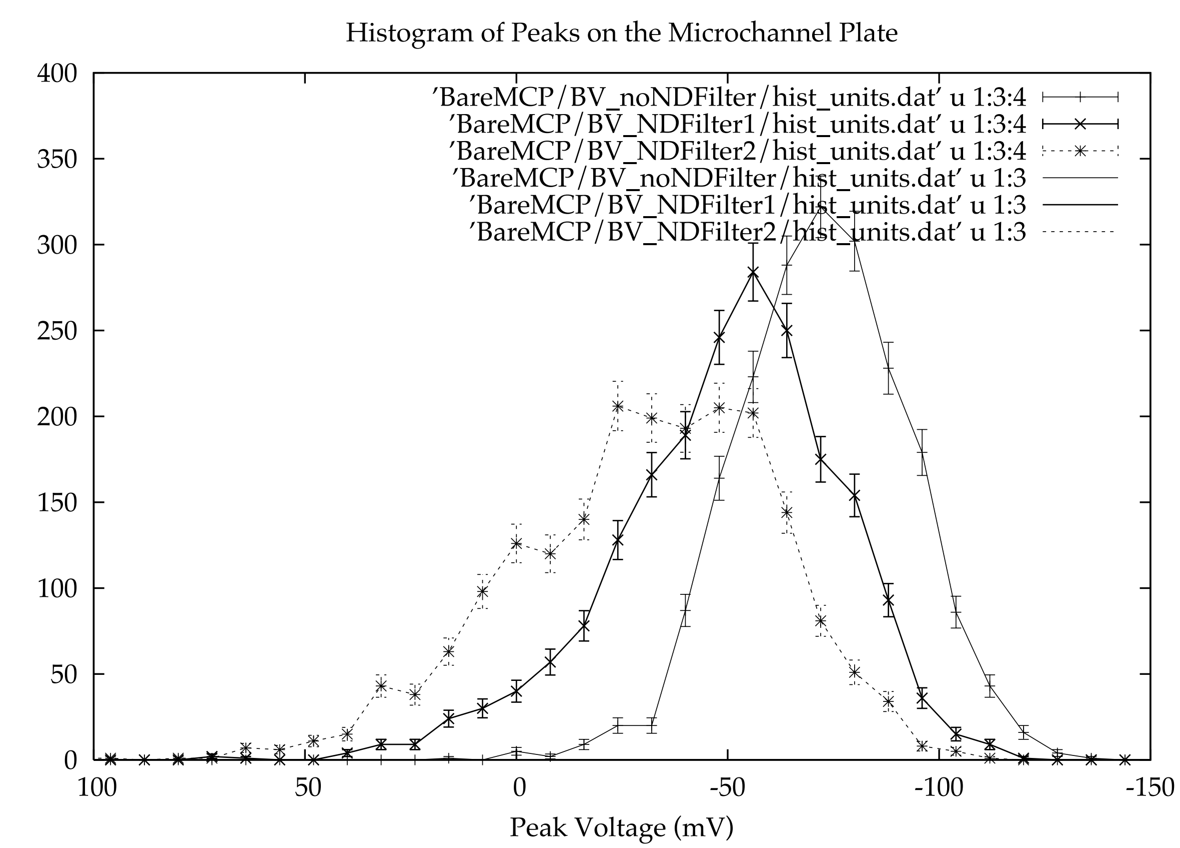
- System now can be reconfigured for HPMT reflection mode measurement, or MCP bias and measurement.
- Two HV feedthroughs (to wafer carousel and ring), allow flexibility for bias and preamp connections.
- HV bias series resistor gives approximate MCP resistance (≈200 MΩ)

Single 33mm ALD-coated MCP Measurements



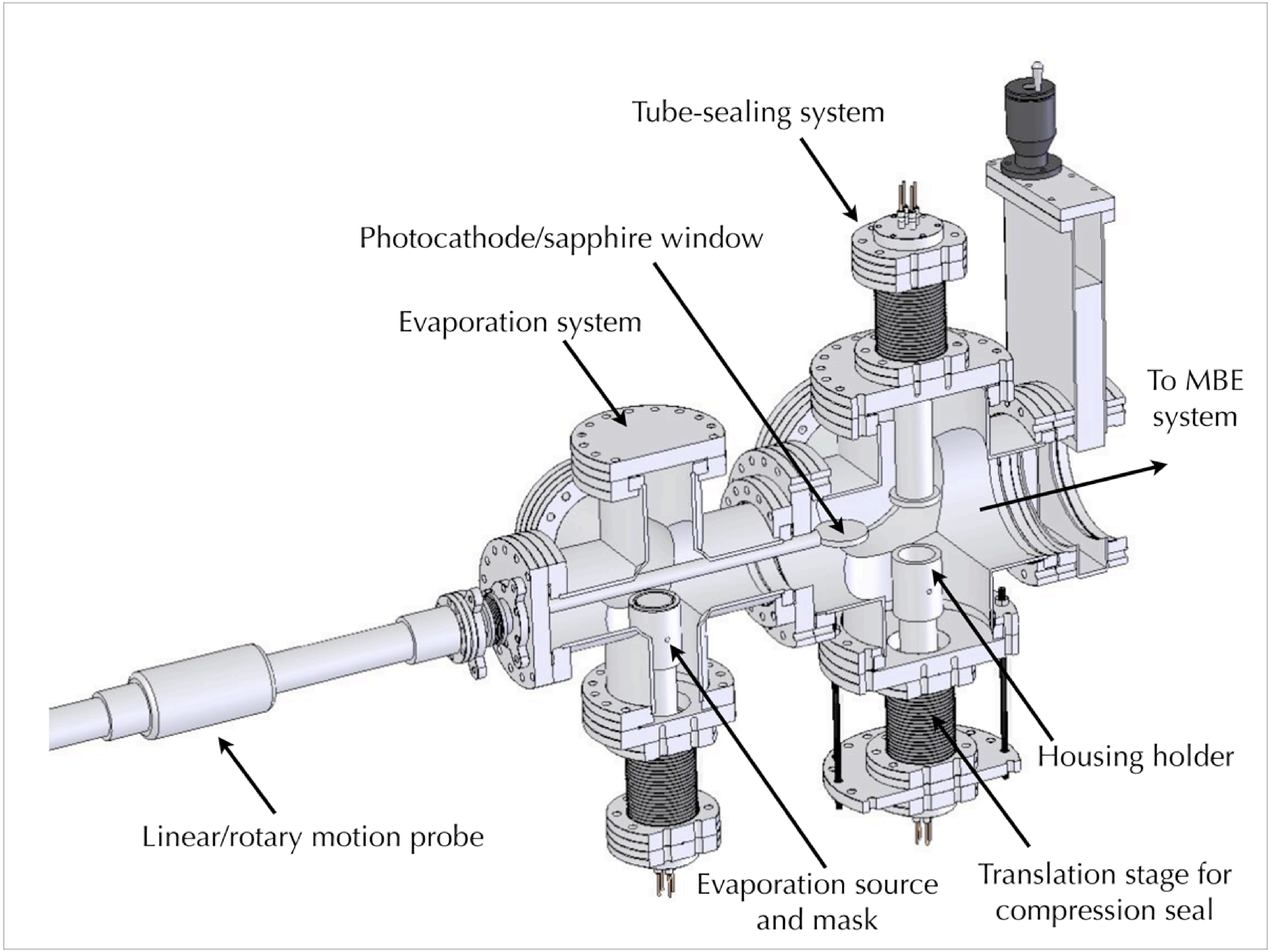


$$v = g \cdot N_{\mathrm{pe}}$$

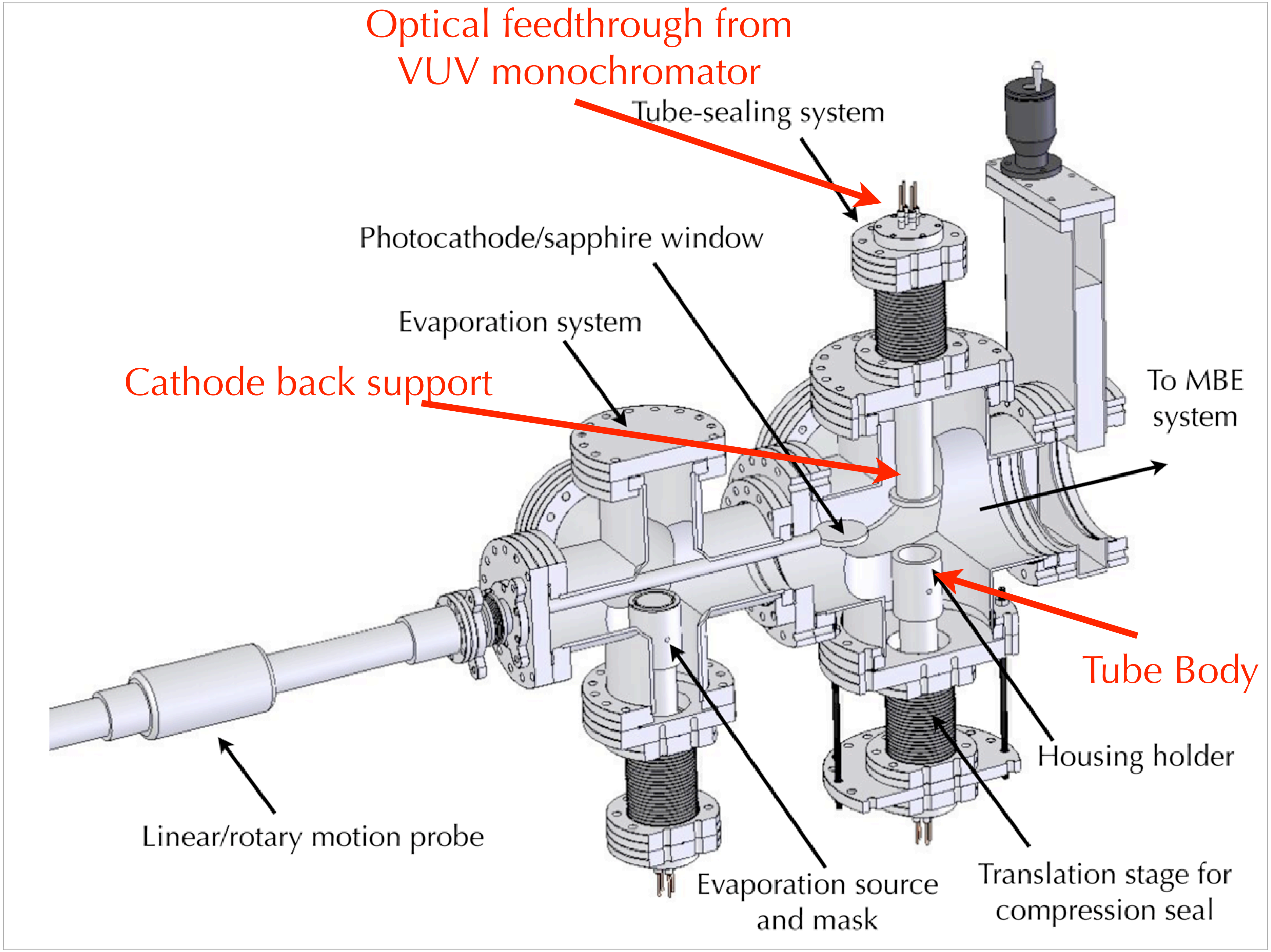


- *Above left:* Average traces with varying optical attenuation (λ=250 nm, 1200V bias)
- *Below left:* Pulse height distribution for corresponding attenuation.
- *Above:* pulse heigh RMS variation versus pulse height

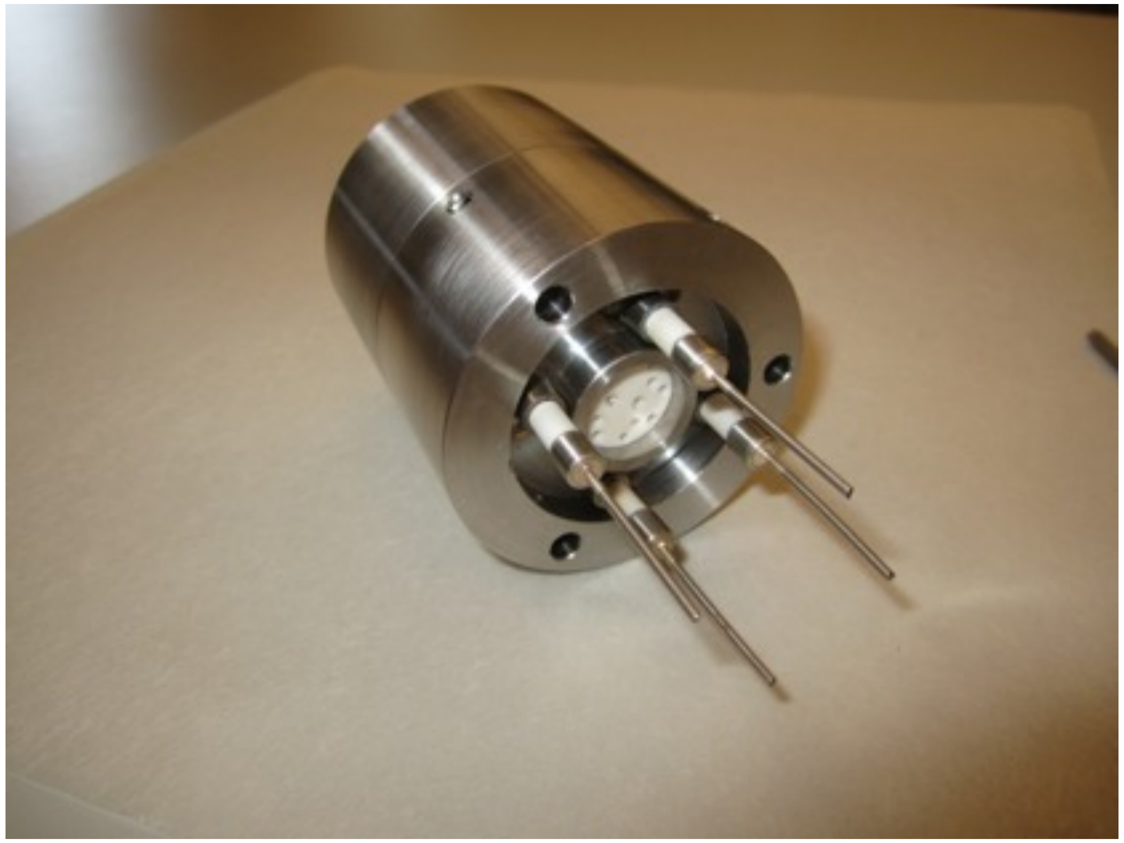
Tube Sealing/VUV Measurement System



Tube Sealing/VUV Measurement System



Tube Body Docking Connector

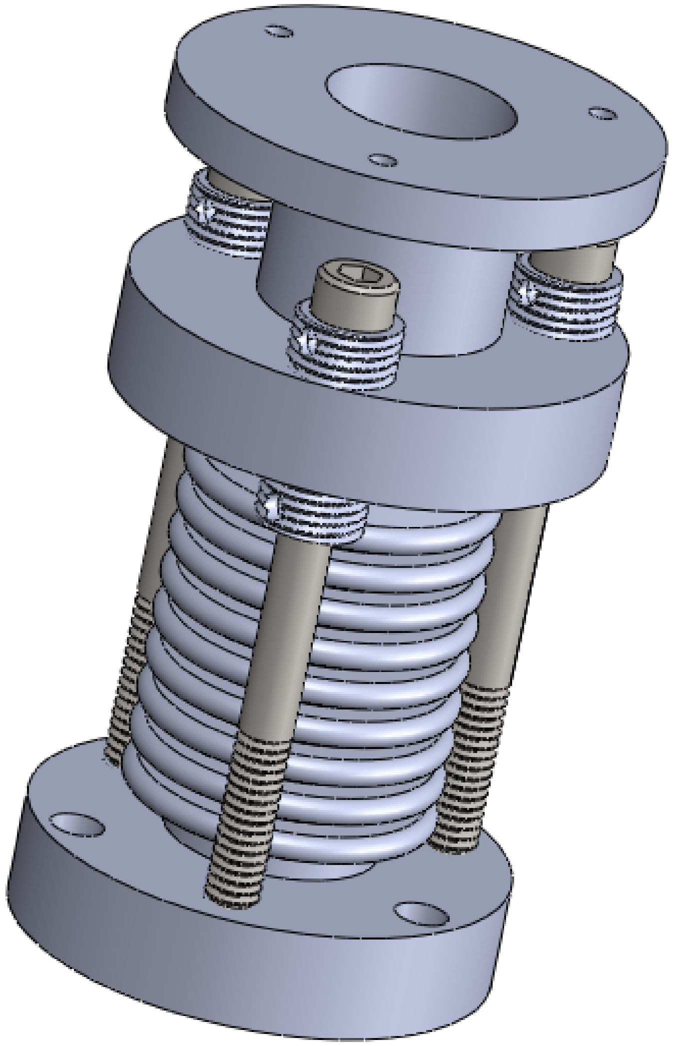


- *Right:* Docking connector with small vertical travel, one side lock (with set screw), HV and signal feed-throughs.

- *Left:* Application specific adaptor with docking interface, and tube body holder

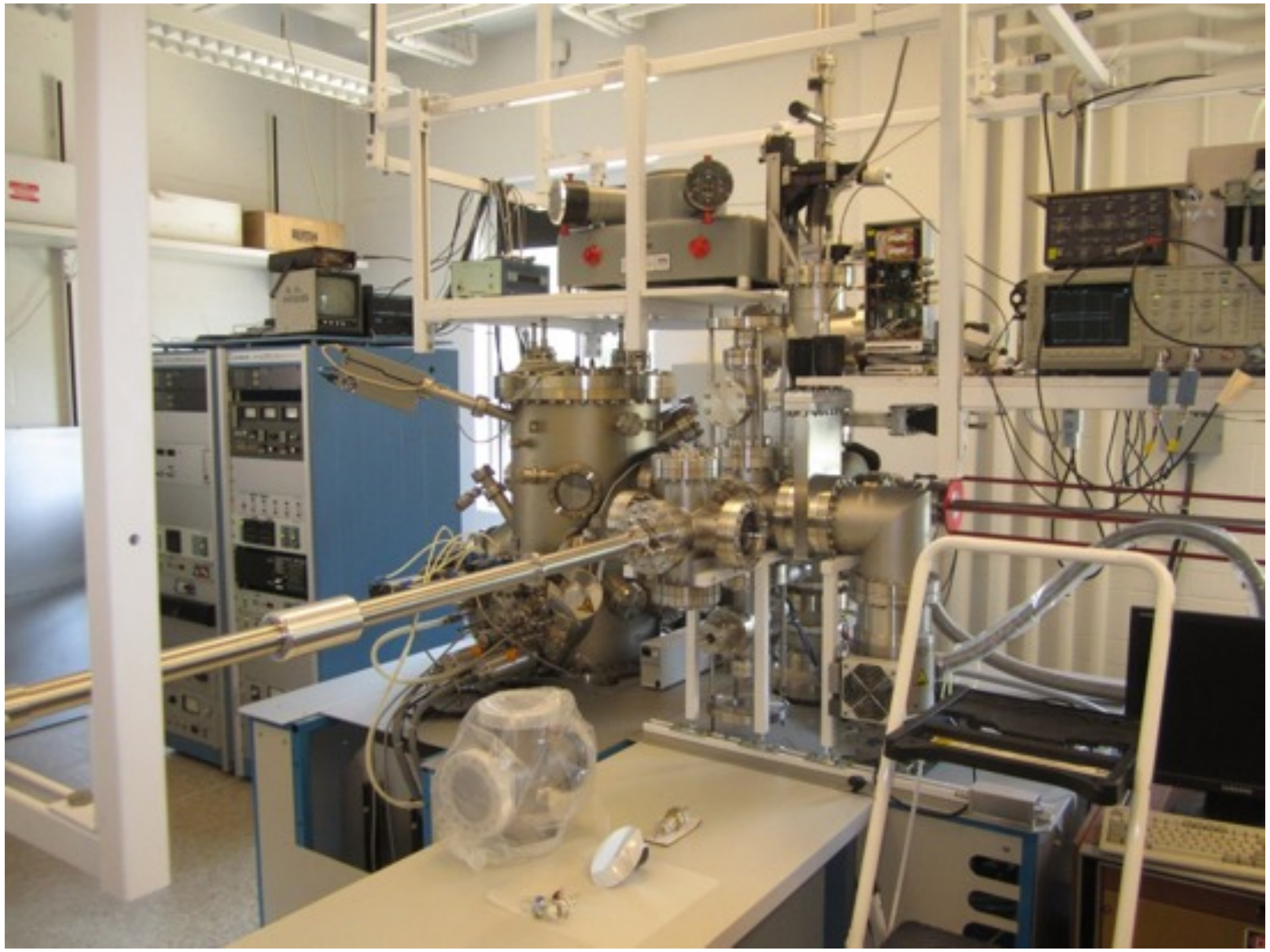
- Robust design to allow application of a significant force for sealing in vacuum

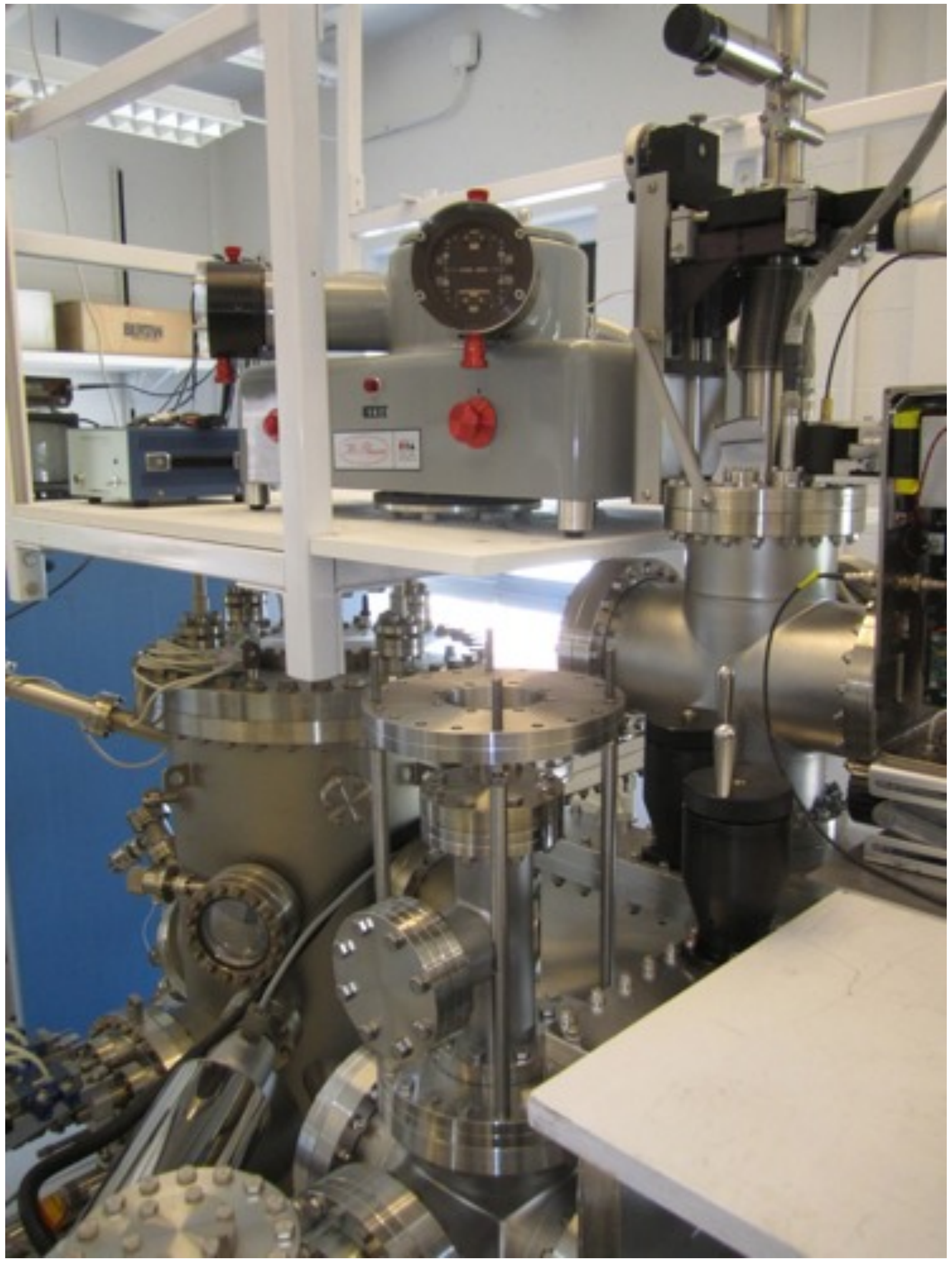
Tube Sealing Components



- Cathode side of tube sealing press with bellows for preload, angular misalignment

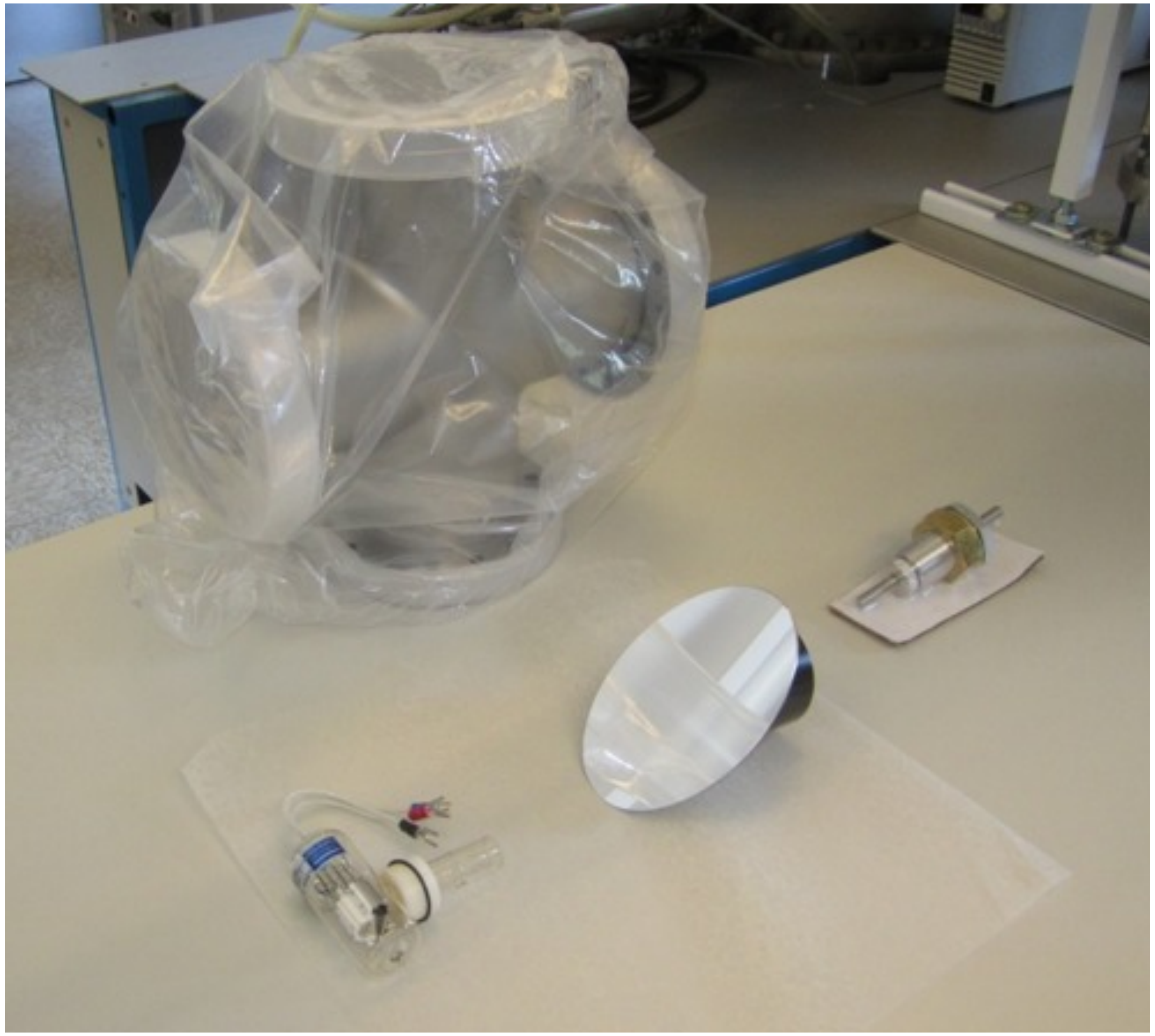
Vacuum Monochromator





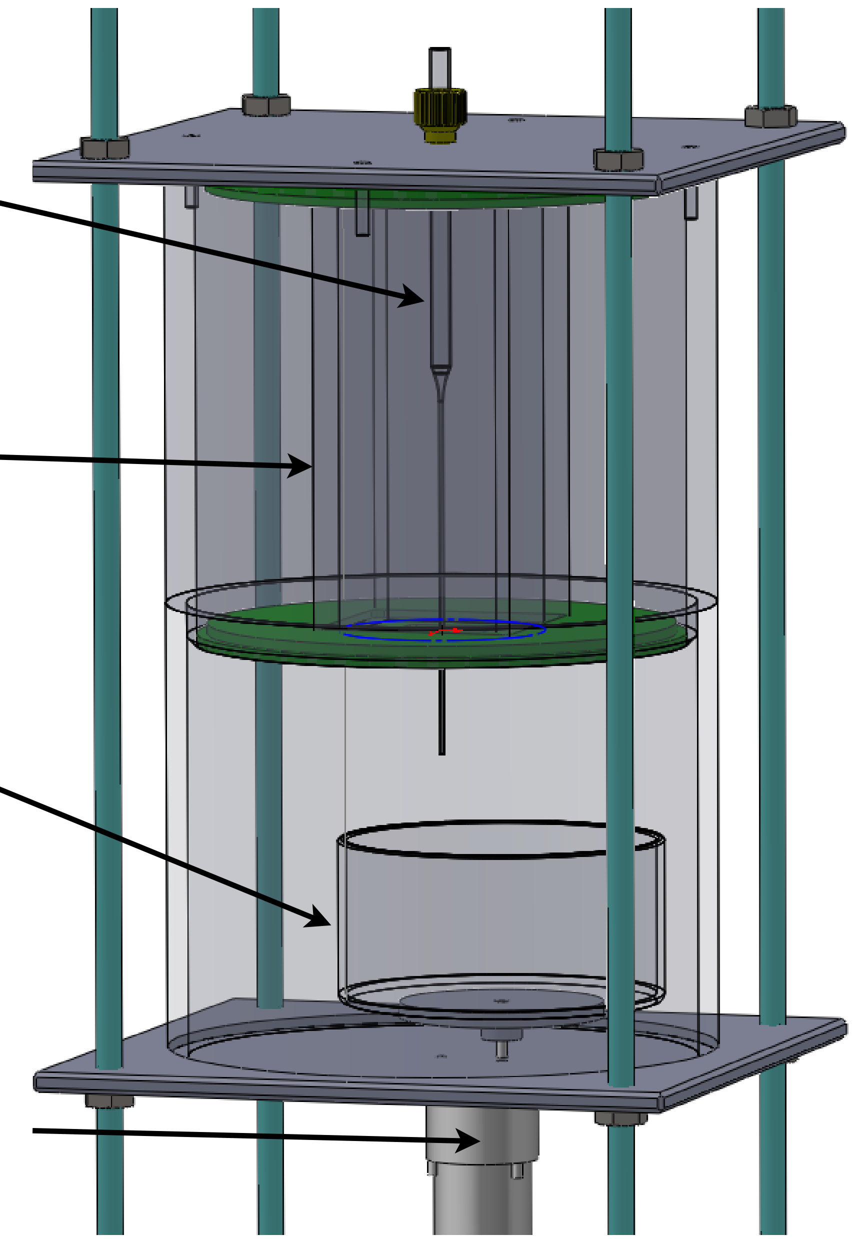
- VUV monochromator mounted on platform.
- Mechanical components for light source, optical chopper, and flip-mirror under development

VUV Optical System Components



- Components for system including vacuum chamber cross, off-axis parabolic condensor/flip mirror, mirror rotation feedthrough, and Deuterium lamp.

Oxide-free Indium Wire System



Conclusions / Future

- Making good progress on demonstrating robust, large area amorphous cathodes with extended long-wavelength response
- Developed viable methods for cathode transfer
- Demonstrated in-situ MCP bias/QE measurement system.
- Close to putting first cathodes on ANL ALD-coated MCPs!
- Possible Future directions:
  - Development of low-background PMTs with UV-response for liquid noble detectors (175 nm for Xenon, 125 nm for Argon). May need to use new MCP substrates since glass typically has high radioactive backgrounds.
  - Work with Bob and Karen on photodetectors for future Atmospheric Cherenkov Telescopes like CTA!